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Domestic solar water heating system in Oman: Current status and future prospects

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ABSTRACT

The excessive usage of fossil fuels worldwide is causing environmental problems. One solution to these problems is the exploitation of available renewable energy resources, including solar energy. This exploitation of renewable energy resources becomes essential to meet the large energy demand that resulted in depletion of fossil fuel resources, fuel price uncertainty and volatility, and growing concerns about global warming. Oman is located in a geographical region with an abundant and reliable supply of solar energy throughout the year. This paper presents a thorough financial, economic and technical analysis of using Solar Water Heaters (SWHs) in residential units. It was found that using SWHs in all governorates of Oman can save up to 1859 GWh of electrical energy annually, which is equivalent to the annual energy produced by a power station of 212 MW size. Moreover, the net annual reduction in CO_2 emission exceeds 1.227 million tons. In addition, the economic feasibility of installing SWHs in residential units is presented. The study shows that the dissemination of SWHs in Oman requires setting policies that motivate people to use them. Besides, subsidies to SWHs customers and/or investors will help making the price of these devices more affordable to the public.

Contents

1. Introduction

There are several factors that determine the level of energy consumption in a given society. These factors include population growth, economic performance, and technological developments. Moreover, governmental policies concerning energy will certainly play a key role in the future level and pattern of energy production and consumption [1].

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Environmental pollution depends on the amount of energy consumption and the process of energy conversion. Several potential solutions to the current environmental problems have been developed, including harnessing renewable energy as well as the utilization of energy conservation technologies. Today, many countries around the world consider wind, solar and other renewable energy technologies as the key to a clean energy future. Furthermore, renewable energy systems can have a beneficial impact not only on environment but also on economic and political issues of the world.

Renewable energy resources delivered approximately 20% of global electricity supply in 2010, and by early 2011 they encompassed 25% of global power capacity from all sources [2]. Global wind power capacity installations reached a value of 198 GW in 2010, whereas the global existing PV capacity increased to around 40 GW in 2010 [2].

Solar heating capacity increased to reach approximately 185 GW thermal in 2010 to provide both water and space heating [2]. Solar water heating technologies are well-known and contributing significantly to hot water production in several countries, lowering energy bills, and reducing the environmental pollution. China, Germany, Turkey, India, and Australia took over the market for newly installed capacity during 2009, with China, Turkey, Germany, Japan, and Greece taking the lead for total installations by the end of that year [2].

The total solar energy resources in Oman are huge and can satisfy all energy demands as well as provide significant export potential [4]. Several studies on solar energy resource assessment were published [5–17]. In [18] a practical case study was conducted considering a solar PV power plant of 5 MW at 25 locations in Oman. The global average value for solar radiation in the 25 locations is more than 5 kWh/m^2/day. The performance and the potential market adoption of SWHs in a number of countries were discussed in details [19–24]. In [25] a preliminary investigation was reported for the potential application of solar water heater for a small area in Oman.

In Oman the residential sector is the largest consumer category for electrical energy with its consumption taking more than half of the total system energy [3]. Part of this electrical energy is used to heat water for almost 5 months a year with an average of 5 h a day. Considering three 50 l water heating units in each residential unit, a huge amount of electrical energy is consumed for water heating. As a result, water heating is consuming a large portion of natural gas; therefore, resulting in polluting the environment. The aim of this paper is to evaluate energy savings, the greenhouse gas emission reduction if the electric water heaters are replaced by solar water heaters in residential sector in Oman. In addition, the economic feasibility of installing SWHs in residential units is presented by a case study.

2. Solar water heater technologies

Solar Water Heating technologies are simple, reliable, and cost-effective methods of harnessing the sun's energy to provide the energy needs for homes and businesses. Solar heating systems are generally composed of solar thermal collectors and a thermal fluid system to transfer the heat from the collector to its point of usage. The working fluid is either pumped (active system) or driven by natural convection (passive system). The system may use electricity for pumping the fluid, and have a reservoir or tank for heat storage and subsequent use. The systems may be used to heat water for a wide variety of uses, including home, business and industrial uses. Solar water heaters can also be classified as open loop or closed loop. The open-loop system circulates water through the collector while the closed loop system uses a heat transfer fluid to collect heat and a heat exchanger to transfer the heat to the storage tank [27].

The collector could be made from a simple glass topped insulated box with a flat solar absorber made of sheet metal attached to copper pipes and painted black, or a set of metal tubes surrounded by an evacuated glass cylinder. In some cases, before the solar energy is absorbed, a parabolic mirror is used to concentrate sunlight on the tube.

Sizing the solar water heating system basically involves determining the total collector area and the storage volume needed to meet the household's hot water requirements. The orientation, size, mounted angle and efficiency of the collector will affect solar water heating system's performance. Solar water heating systems use both direct and diffuse solar radiation.

3. Using of solar water heaters in Oman

Based on 2010 census [28], the total population of Oman is about 2.8 million and there are around 551,058 residential units exist. The total number of residential units in the 11 governorates of Oman is presented in Table 1. This study is limited to residential buildings only; it does not include industrial, commercial and governmental sectors. Almost all residential units utilize electric water heaters with an average of 3 heaters in each one. The attributes in Table 1 is calculated based on the parameters presented in Table 2.

3.1. Results and discussions

Utilizing solar water heaters in all governorates in Oman can save up to 1859 GWh annually, as shown in Table 1. This is

Table 1
Annual energy consumption and energy cost for the residential units in Oman.

Governorate	No. residential units	No. heater	Annual energy saving (MWh)	Capacity saving (MW)	Avoided energy cost (million US $)
Muscat	153,381	460,143	517,660.88	59.1	32.1
North & South Al Batinah	140,638	421,914	474,653.25	54.2	29.4
Musandam	10,764	32,292	36,328.50	4.1	2.3
Dhahirah	29,697	89,091	100,227.38	11.4	6.2
Dakhliyah	63,225	189,675	213,384.38	24.4	13.2
Noth & South Sharqiyah	82,490	247,470	278,403.75	31.8	17.3
Al Wusta	6,387	19,161	21,556.13	2.5	1.3
Dofar	46,774	140,322	157,862.25	18.0	9.8
Al Buraymi	17,702	53,106	59,744.25	6.8	3.7
Total	551,058	1653,174	1859,820.75	212.3	115.3

Table 2
The model input parameters.

Parameter	Value
Water heater rating	1500 W
Number of water heater	3 heaters/unit
Number of hours, heater on	5 h/day
Number of days, heater on	150 day
Annual energy consumption	3375 kWh/year
Cost of energy	0.062US$/kWh [26]

equivalent to the annual energy produced by power station of 212 MW sizes, which represents 2 frame 9 gas turbine generators operating continuously at rated capacity. This means by replacing the existing electric water heaters with solar heaters, it will be possible to develop and expand future industrial applications without the need for new power station in the short term. Almost all of Oman's domestic electric energy consumption is supplied by burning natural gas. The saving in energy production means reduction in natural gas consumption. This saving will strengthen the economy in Oman that depends mainly on oil and gas revenues. The avoided energy cost in different governorates in Oman is presented in Fig. 1.

Table 3 presents the potential reduction in GHG emissions per MWh of electricity for natural gas generation facilities in Oman. These values are calculated based on the default emission factors, provided by UN's Intergovernmental Panel on Climate Change (IPCC) [29], and considering a 10% transmission and distribution (T&D) losses and the efficiencies indicated [4].

The other important gain owing to the use of solar water heaters is the reduction of CO_2 footprint. The net annual reduction in CO_2 emission in all governorates exceeds 1.227 million tons, as depicted in Fig. 2. Considering a damage cost of \$20/tCO_2 as in [4], value of avoided emission is quantified as shown in Fig. 3. The total annual avoided emission cost in all governorates is about \$24.5 million.

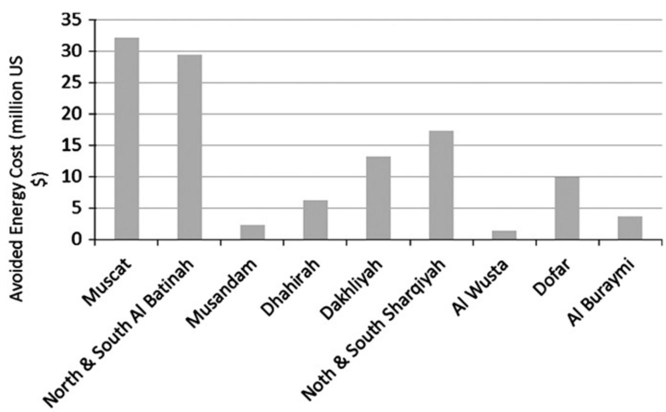


Fig. 1. Avoided energy cost in different governorates of Oman.

Table 3
Assumed properties for CO_2 calculation.

Fuel type	tCO_2 (MWh)	Efficiency	tCO_2/Mwh$_{Electricity}$
Natural gas	0.20196	0.34	0.66

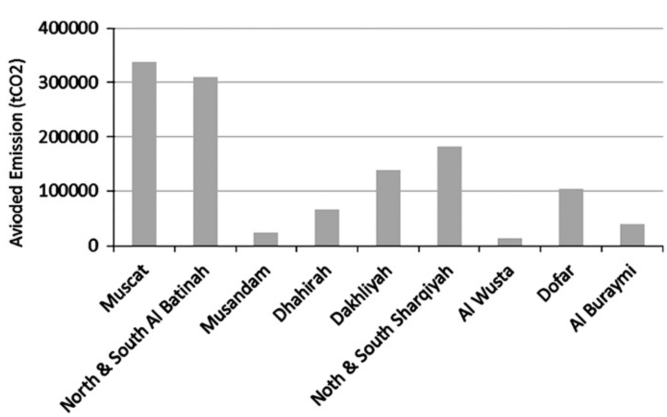


Fig. 2. Annual reduction in CO_2 emission in different governorates of Oman (tCO_2).

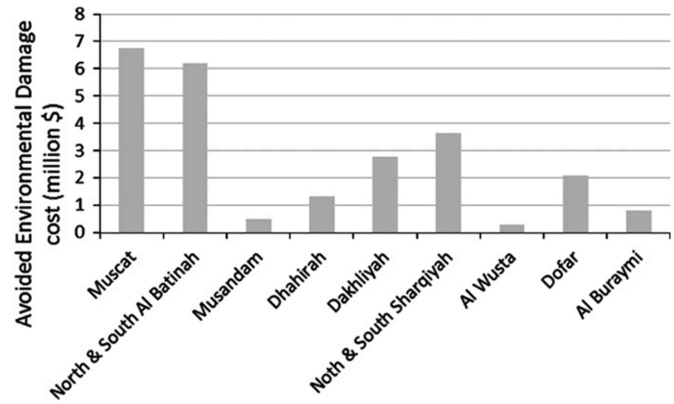


Fig. 3. Annual avoided environmental damage cost in different governorates of Oman.

4. Techno-economic evaluation

In this section, the economic feasibility of installing SWHs in a typical residential unit is tested using four economic indicators.

4.1. Economic evaluation methods

The economic feasibility of the project is evaluated using the following indicators: net present value (NPV), benefit–cost ratio (BCR), internal rate of return (IRR), and the payback period (PP).

4.1.1. Net present value

Due to the time value of money, a hundred dollars today are more valuable than a hundred dollars in the future. The net present value (NPV) approach uses the time value of money to convert future cash flow into a present value at a certain discount rate.

$$PV = \frac{FV}{(1+dr)^N} \tag{1}$$

where PV and FV are the present and the future values, respectively; dr is discount rate, and N is the number of years in the future.

For a recurring constant annual income, the present value can be found using the following formula [30]:

$$PV_A = A\frac{(1+dr)^N - 1}{dr(1+dr)^N} \tag{2}$$

where PV_A is the present value of the recurring annuity, A. The NPV of a project is the difference between revenues and costs in today's money. In any comparison of investing options, the project with the maximum NPV is the winning one.

4.1.2. Benefit–cost ratio

The benefit–cost ratio (BCR) is the ratio of the net benefits to costs of the project. Benefits are obtained by summing the present value of annual income, while the cost include capital cost expenditures, O&M costs, replacement costs and taxes, if any. Ratios greater than 1 are indicative of profitable projects. When comparing between different investing options, the project with the maximum BCR is the winning one. Therefore, when ranking different projects, the net BCR leads to the same conclusion as the NPV indicator.

4.1.3. Internal rate of return

Mathematically, internal rate of return (IRR) is defined as the discount rate that gives an NPV of zero. IRR is the effective annual return of investment over the life of the project. Therefore, the project will have value for investors if its IRR is greater than the discount rate. When using IRR for project ranking, the project with the highest IRR is the winner.

4.1.4. Payback period

Payback period (PP) is defined as the length of time required to recover the initial investment in a project. The shorter the length, the more economically attractive to investors the project is. Although simple PP is easy to understand, it does not account for the time value of money; therefore, it has serious limitations. Using discounted cumulative cash flow, better results can be achieved. Renewable energy investments have intensive capital costs, therefore, relatively long payback periods.

4.2. Economic assumption

Table 4 shows the cost of the economic assumptions considered in this study.

4.3. Results and discussions

Considering the parameters presented in Table 2, replacing the 3 electric water heaters by a solar water heater yields an annual saving of about $209. The benefit of this investment is represented by the present value of this cash flow, calculated using Eq. (2). The total cost associated with the project includes the initial cost in addition to the present value of the operation and maintenance cost. The cash flow of the project is presented in Fig. 4.

The annual cash flow (ACF) starts with a high capital cost, at year zero. Starting from year 1, a positive net cash flow occurs annually as a result of earnings from energy saving (+$209), and O&M costs (−$15). At year 25, a higher cash flow occurs because of the project salvage value (+$100).

The NPV of the project is represented by the difference between the present value of the positive and the negative cash flows. Having a present value of the benefits of $2007 and a present value of costs of $1471, the NPV of the project is $536. The ratio of the benefits' present value to that of the costs (BCR) is 1.36.

The simple payback period is about six years, as shown by the cumulative cash flow (CCF). The discounted value of a specific cash flow is obtained using Eq. (1). Using discounted cumulative cash flow (DCCF), a 10-year payback period is obtained, which represents a more realistic figure. The value of the discounted cumulative cash flow at year 25 represents the NPV of the project.

Fig. 5 presents the NPV of the project as a function of the discount rate (*dr*). The IRR of this project is 16.7%.

Table 4
Cost and economic factors of the SWH.

Item description	Cost (US$)
Total initial cost	$ 1350
Down payment	$0
Annual O&M	$15
Inflation rate	3%
Discount rate	7.55%
Life time	25 years
Salvage value	$100

5. Conclusions

Solar water heaters are technically feasible in Oman weather conditions. This paper demonstrates that using SWHs in all governorates in Oman can save up to 1859 GWh annually, which is equivalent to the annual energy produced by a power station of 212 MW size operating at rated output. Moreover, the net annual reduction in CO_2 emission exceeds 1.227 million tons. The economic feasibility of installing SWHs in a typical residential unit is tested using four economic indicators; net present value (NPV), benefit–cost ratio (BCR), internal rate of return (IRR), and the payback period (PP). The simple payback period for the typical residential unit was about six years. Besides, using discounted

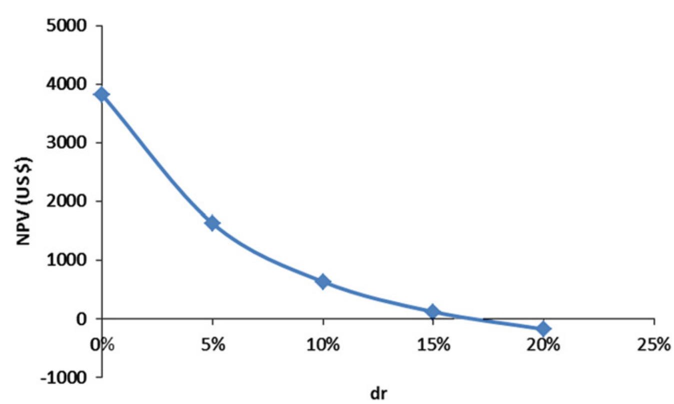


Fig. 5. Effect of discount rate on the NPV of the project.

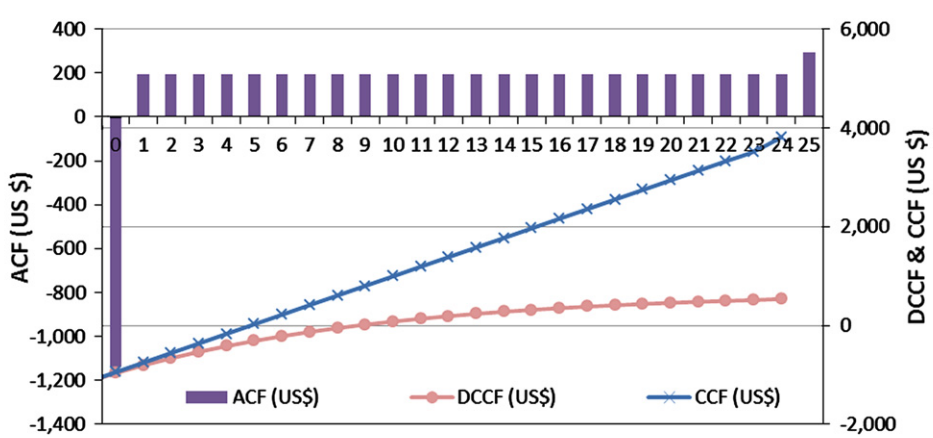


Fig. 4. Cash flow analysis of the project.

cumulative cash flow, a 10-year payback period was obtained, which represents a more realistic figure.

It is recommended that the Government adopt supports policies that motivate people to use SWHS to save natural gas reserves and the environment. For example, the government should introduce subsidies to SWHs customers and/or investors helps making the price of the SWHs more affordable to the public. In addition, a media campaign to educate people that SWHs are economical, environment friendly and last for long time would help adopting these technologies.

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